Radioisotope Production Utilizing HANARO Reactor in KAERI

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Introduction

Facilities for Radioisotope Production in KAERI
  - Reactors
  - RI production facilities

Process for Radioisotope Production
  - Target Preparation
  - Irradiation Process and Tools
  - Sealed Source Fabrication

Development of Radioisotopes in KAERI

Quality Control

Transportation of Radioisotopes

Production and Supply of Radioisotopes in KAERI

Future Direction
Korea Atomic Energy Research Institute (KAERI) have played a key role in radioisotope production and its applications utilizing nuclear reactors for more than 40 years.

HANARO project was launched in 1985 and initial criticality of HANARO was reached in 1995.

In 1995, Korean government established “a comprehensive promotion plan for utilization, research and development of radiation and radioisotopes”.

In 2002, the nation-wide demand of RIs was more than 250 kCi and number of organizations utilizing radioisotope and radiation are over 2,000.

For stable supply of radioisotopes, Korean government is carrying out a feasibility study on the construction of a new research reactor fully intended for the mass production and back up supply of radioisotopes.
Brief History of RI Production in KAERI

1960’s
- Acquisition of RI Manufacturing & Production License from Ministry of Health: Au-198 Colloid & I-131
- Construction of 4 Lead Hot Cells for the RI Production
- Launching of RI Production

1970’s
- Acquisition of RI Production: P-32, Cr-51 & Tc-99m
- Construction of 2 Concrete and 10 Lead Hot Cells
- Supply of Ir-192 for Non Destructive Testing

1980’s
- Acquisition of RI Sale License from MOST
- Supply of Solvent Extraction Equipment of Tc-99m to Hospitals
- Supply of Au-198 Colloid, I-131, Tc-99m, Mo-99, Cr-51 & P-32
- Supply of Tc-99m Cold Kits

1990’s
- Acquisition of RI Production License from KFDA: I-131 Capsule & Examethazime
- Establishment of RIPF & Clean Room Facility
- Supply of Ho-166 & Ir-192 to Hospitals

2000 ~
- Oversea Marketing of I-131, Ir-192 & Co-60
- Development of CNS Imaging Agent
- Supply of 99mTc Generator
- Acquisition of ISO 9001:2000 for RI Production and Service
- Acquisition of Nuclear Safety Mark (Ir-192 NDT Assembly)
Radiation Technology (RT) Policy

- **CNEPP (Comprehensive Nuclear Energy Promotion Plan)**
  - Five year term plan, started in 1997
  - Goal
    - Enhancing economic growth, environment protection, public welfare and S&T development through peaceful and safe use of nuclear energy
  - Estimated Budget Requirement
    - 1,549 billion Won for the 2nd phase

- **CRRPP (Comprehensive Radiation and RI Promotion Plan)**
  - Started in 1997
  - Revising for 7 year plan : 2005~2011
    - Estimated budget requirement : 500 Billion Won
    - Objectives
      - Promote RT as one of major domestic industry
    - Scope
      - Utilization and applications, R&D, human resource, institutions, etc.

- **Act on the Utilization of Radiation and RI**
  - Enacted in 2002
  - Objectives
    - Secure RT research fund
    - Formulate related industries and manpower development
    - Promote to establish RT R&D Center under KAERI by 2005
The Korea Atomic Energy Research Institute (KAERI)

- The nation's sole nuclear research institute
- RI production and its application is one of main activities

History of radioisotope production in KAERI

- TRIGA Mark-II (250 kW, 1962~1995) in Seoul
- HANARO (30 MW, 1996~ ) in Daejeon
HANARO Reactor for Radioisotope Production

HANARO Reactor

Reactor Type: Open Tank in Pool
Thermal Power: 30 MWth
Fuel: U₃Si - Al 19.75 w/o ²³⁵U
Coolant: H₂O
Moderator: H₂O / D₂O
Reflector: D₂O
Cooling Method: Convective Up-flow
Secondary Cooling: Cooling Tower
Max. Neutron Flux: 5x10¹⁴ n/cm²/sec

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## HANARO Reactor for Radioisotope Production

<table>
<thead>
<tr>
<th>Region</th>
<th>Symbol</th>
<th>Number</th>
<th>Thermal Neutron Flux (n/cm²/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Core</td>
<td>CT</td>
<td>1</td>
<td>~ 4.0×10^{14}</td>
</tr>
<tr>
<td></td>
<td>IR</td>
<td>2</td>
<td>3.0 ~ 4.0×10^{14}</td>
</tr>
<tr>
<td>Out Core</td>
<td>OR</td>
<td>4</td>
<td>2.0 ~ 3.0×10^{14}</td>
</tr>
<tr>
<td>Reflector</td>
<td>HTS</td>
<td>1</td>
<td>8.8×10^{13}</td>
</tr>
<tr>
<td></td>
<td>IP</td>
<td>17</td>
<td>2.4 ~ 15.0×10^{13}</td>
</tr>
<tr>
<td></td>
<td>NAA</td>
<td>3</td>
<td>3.6 ~ 16.0×10^{13}</td>
</tr>
</tbody>
</table>
Facilities for Radioisotope Production in KAERI
Layout of Radioisotope Production Facility (RIPF)
## Overview of Principal Radioisotope Production Facilities

<table>
<thead>
<tr>
<th>Facility</th>
<th>Specification (W×D×H, mm)</th>
<th>Number /area</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank I</td>
<td>Concrete hot cell, 2800×2500×4500</td>
<td>4</td>
<td>Sealed source preparation</td>
</tr>
<tr>
<td>Bank II</td>
<td>Lead hot cell, 2400×1400×1500</td>
<td>11</td>
<td>Development of radioisotopes</td>
</tr>
<tr>
<td>Bank III</td>
<td>Lead hot cell, 400×1400×1500</td>
<td>6</td>
<td>Radiopharmaceutical preparation</td>
</tr>
<tr>
<td>Bank IV</td>
<td>Lead hot cell, 1490×1150×1260(3), 1260×1190×1260(1)</td>
<td>4</td>
<td>$^{99}$Mo/$^{99m}$Tc generator preparation</td>
</tr>
<tr>
<td>Co-60 storage pool</td>
<td>SUS lining, 3000×4500×6000</td>
<td>1</td>
<td>Co-60 storage</td>
</tr>
<tr>
<td>Clean Room Facility (1st floor)</td>
<td>- Clean class 10000 (Service area of lead hot cells)</td>
<td>60 m²</td>
<td>Radiopharmaceutical preparation</td>
</tr>
<tr>
<td>Clean Room Facility (2nd floor)</td>
<td>- Clean class 10000  - Clean class 100000(Cold kit lab)</td>
<td>136 m² 134 m²</td>
<td>Cold kit preparation</td>
</tr>
</tbody>
</table>
Facilities for Radioisotope Production in KAERI
Hot Cell for RI Production

- Hot Cell **BANK1**
  - 4 concrete cells ($^{60}$Co, $^{192}$Ir)

- Hot Cell **BANK2**
  - 11 lead cells ($^{32}$P, $^{99m}$Tc, $^{51}$Cr, $^{192}$Ir for RALS, etc.)

- Hot Cell **BANK3**
  - 6 lead cells ($^{131}$I, $^{166}$Ho, $^{125}$I)

- Hot Cell **BANK4**
  - 4 lead cells ($^{99}$Mo/$^{99m}$Tc generator)
Facilities for Radioisotope Production in KAERI
Layout of Radiopharmaceutical Facility
Facilities for Radioisotope Production in KAERI
Clean Room Facilities in RIPF

Auto Clave installed in Clean room
Preparation Room for Cold Kits
Vial Washing System
Water Purification System
Process for Radioisotope Production

General Process of Radioisotopes

- Target Preparation
- Irradiation
  - Chemical Processing
  - Assembling/welding
- Quality Control
- RI Products
- Active Material
- Supply
Target Preparation

- Inner/Outer capsule
- Cold welding for inner capsule
- Vacuum bubble leak test
- TIG welding for outer capsule
- Irradiation Target
- He leak test
- He charging & pin hole welding
Target Preparation

- Inner/Outer Capsule for IP
Target Preparation

- Inner/Outer Capsule for mass production of Ir-192
Target Preparation

- Inner/Outer Capsule for HTS
Irradiation Tools

- Outer/Inner Region RIG

Outer Region (OR) Rig

Inner Region (IR) Rig
Irradiation Tools

- Loading/Unloading Tools for IP Irradiation Capsule
Irradiation Tools

- Loading/Unloading Tool for IP RIG
Sealed Source Fabrication
(Target Preparation)

Target Preparation

Irradiation target for $^{192}$Ir NDT Source Production

Irradiation Target
For $^{192}$Ir NDT source

Irradiation Target
For $^{192}$Ir HDR source
Sealed Source Fabrication
(Fabrication & Welding Process)

- Fabrication
  - Welding method
    - TIG or Plasma welding: Ir-192, Co-60 Industrial and gauge sources
    - Laser welding: Ir-192 HDR sources

- Welding Equipments

  TIG welding  Plasma welding  Laser welding
## R&D Program of Reactor Radioisotopes

<table>
<thead>
<tr>
<th>Type</th>
<th>Developed</th>
<th>Under development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-sealed sources</td>
<td>99\textsuperscript{m}Tc, 99\textsuperscript{m}Mo, 131\textsuperscript{I}</td>
<td>125\textsuperscript{I}, 33\textsuperscript{P}, 89\textsuperscript{Sr}, 153\textsuperscript{Sm}, 186\textsuperscript{Re}, 188\textsuperscript{Re}</td>
</tr>
<tr>
<td></td>
<td>166\textsuperscript{Ho}, 165\textsuperscript{Dy}, 198\textsuperscript{Au}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>51\textsuperscript{Cr}, 32\textsuperscript{P}</td>
<td></td>
</tr>
<tr>
<td>Sealed sources</td>
<td>192\textsuperscript{Ir}, 60\textsuperscript{Co}</td>
<td>152\textsuperscript{Eu}, 169\textsuperscript{Yb}, 75\textsuperscript{Se}, 170\textsuperscript{Tm}</td>
</tr>
</tbody>
</table>
Development of Ir-192 NDT Sources

- In 2001, certification for special form of radioactive material was obtained from the Korea Institute of Nuclear Safety (KINS).

- The technology was transferred to private company and high specific sources (> 50 Ci/source) are produced utilizing the HANARO reactor.

- The Korean national demand for $^{192}$Ir for NDT: around 70 kCi/year

- Around 6 ~ 8 kCi/month of $^{192}$Ir sources are supplied to domestic and international users currently.
Development of Ir-192 NDT Sources

Industrial Sources

192Ir Radiographic Source Assembly

Fabrication System for 192Ir Radiographic Source
Development of Co-60 Sealed Sources

- **60Co sealed source for gauge**
  - The activity of 60Co gauge source supplied by KAERI ranges from 1 mCi to around 1 Ci
  - 60Co gauge sources are produced according to user requests

- **60Co sealed source for food irradiation**
  - A feasibility study on a joint venture among KAERI, KHNP (Korea Hydro-Nuclear Power Company) and a private company was carried out
  - Cooperation scheme
    - Private company: Marketing
    - Conversion of 59Co: KHNP’s Wolsung nuclear power plant
    - Fabrication of cobalt sources: KAERI’s hot cells
  - Expectation: Production of several million curies in 2005
  - Final decision has not been made until now.
Development of Co-60 Sealed Sources

60Co Sealed Sources

60Co sealed sources for gauge

60Co sealed sources for food irradiation

Fabrication system of 60Co large source

60Co Fabrication system installed in hot cell
Development of Medical Sealed Sources
(Over View)

- **192Ir seed**
  - A therapeutic 192Ir seed (0.5mm diameter and 3.0mm length) produced using TRIGA Mark III since 1987
  - Production in HANARO reactor utilizing hydraulic transfer system

- High dose rate 192Ir sources (1.1mm, 3mm and 4mm in diameter)
  - Preparation of a laser welder and automatic welding jigs for fabrication of micro source
  - Preparation of a TIG welder and pressing machine
  - 10 Ci sources (4mm in diameter) supplied to domestic hospitals for substitution with the 60Co brachytherapy sources
Development of Medical Sealed Sources
(Over View)

192Ir HDR Source, φ 1.1 mm

192Ir HDR Source, φ 4.0 mm

192Ir HDR Source, φ 3.0 mm

192Ir HDR Source Fabrication System installed in Hot Cell

Welding System for 192Ir HDR Source

Fabrication System with Pressing machine

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Development of Medical Sealed Sources

(\(^{192}\)Ir HDR Source)

Overview

- Development of laser welding techniques for fabrication of micro source

<table>
<thead>
<tr>
<th>Radioactive Source</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Iridium-192, metallic cylindrical configuration</td>
</tr>
<tr>
<td>Iridium-192 pellet-HDR</td>
<td>Diameter 0.6 mm Length 3.5 mm</td>
</tr>
<tr>
<td>Capsule-HDR</td>
<td>Diameter 1.1 mm Length 5.2 mm</td>
</tr>
<tr>
<td>Initial nominal activity-HDR</td>
<td>370 GBq (10 Ci)</td>
</tr>
<tr>
<td>Maximum activity-HDR</td>
<td>444 GBq (12 Ci)</td>
</tr>
<tr>
<td>Air Kerma Rate</td>
<td>41.71 mGy/h ±5% at 1 m</td>
</tr>
</tbody>
</table>

Source Wire

- Source: Encapsulated Iridium-192 in stainless steel capsule
- Driving Cable: flexible stainless steel wire (1.1Dx2000L, mm)
- Manufactured according to ISO 9001:2000

Ir-192 HDR Source for RALS
Development of Medical Sealed Sources
\(^{192}\text{Ir HDR Source}\)

- **Overview**
  - Elements of RALS source assembly designed by KAERI
  - Comparing to competitive company’s good

Source produced by KAERI

Source produced by Gamma-Med

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Development of Medical Sealed Sources

\(^{192}\text{Ir HDR Source}\)

- Automatic fabrication system

<table>
<thead>
<tr>
<th>Production Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hot Cells</strong></td>
</tr>
<tr>
<td>• 2 lead hot cells for Ir-192 (RALS)</td>
</tr>
<tr>
<td>• Size (cm): 160Lx140Wx240H</td>
</tr>
<tr>
<td>• Shielding (cm): 15</td>
</tr>
<tr>
<td>• Set of manipulators</td>
</tr>
<tr>
<td><strong>Automatic Fabrication System</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wire loader</td>
</tr>
<tr>
<td>• End cap loader</td>
</tr>
<tr>
<td>• Laser beam head</td>
</tr>
<tr>
<td>• Rotating jig welder</td>
</tr>
<tr>
<td>• Polishing part</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ir-192 source loader - 12 sets</td>
</tr>
<tr>
<td>• Rotating jig welder</td>
</tr>
<tr>
<td>• Assembly release unit</td>
</tr>
<tr>
<td>• Storage vat</td>
</tr>
<tr>
<td>• Production rate: 8 pc/batch/hr</td>
</tr>
</tbody>
</table>

Welding System for \(^{192}\text{Ir HDR Source}\)

\(^{192}\text{Ir HDR Source Fabrication System installed in Hot Cell}\)

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Development of Medical Radioisotopes

**166Ho based radiopharmaceuticals**

- Development of 166Ho therapeutic agents
  - The 166Ho-chitosan complex for liver cancer
  - The 166Ho-patch for skin cancer treatment
  - 166Ho-balloons for the prevention of the restenosis of the coronary artery
    - A radioactive liquid-filled balloon
    - A new radioactive coated balloon
  - The 166Ho-Stent for esophageal cancer

![Images of 166Ho-CHICO, 166Ho-Patch, 166Ho-DTPA balloon, and 166Ho-Stent]
Development of Medical Radioisotopes

Solution and Capsule of $^{131}$I

- Production status of $^{131}$I
  - 1987~1992: The development of dry distillation process from an irradiated TeO$_2$ target
  - Specific activity of $^{131}$I solution: 3 ~ 5 Ci/ml
  - Production of therapeutic capsules: from 30 to 200 mCi/capsule
  - Production amount: 30~ 50 Ci/batch
Development of Tc-99m Generator

- **Status**
  - More than 200 gamma cameras in about 100 hospitals in Korea
  - The introduction of foreign technologies for the $^{99m}$Tc generator production

- **Development of generator loading facility (GLF)**
  - For installation of GLF, around 120 m² of space were prepared in the hot cell area
  - KAERI installed the $^{99m}$Tc Generator Loading Facility in accordance with the regulation of KGMP in 2003
  - Supply > 200 generators per week for users in 2004
Development of Tc-99m Generator
(Production Line)

Front View

Rear View
Development of P-32 and P-33

- Development of sublimation methods for production of phosphorus radionuclides

- Installed apparatus for $^{32}$P production

- New apparatus for $^{32}$P production

- Alternative sublimation method for production of $^{32}$P and $^{33}$P under low pressure
Development of Cr-51 & Sr-89

- Development of a method of $^{51}$Cr preparation based on an enriched target
- Study on a new $^{89}$Sr separation method from irradiated Y$_2$O$_3$ target using crown ether and n-octanol
Development of Other Radioisotopes

- Basic experiments for $^{125}$I production by a loop-batch type apparatus
- Development of detector calibration sources using $^{137}$Cs, $^{60}$Co and $^{152}$Eu
Quality Control

- ISO system was established for sealed radiation source production
  - First approval date: Nov. 2000
    ISO9002:1994
  - Revision Date: Dec. 2003
    ISO9001:2000

- Applied Standards for Certification of Sealed Source Manufacturing
  - IAEA Safety Regulation
  - U.S. Code of Federal Regulation
  - ISO Standards
  - Domestic Safety Regulation (MOST)
## Specification of Transport Shielding Container used in KAERI(2)

<table>
<thead>
<tr>
<th>Model</th>
<th>¹⁹²Ir projector</th>
<th>Container for ¹⁹²Ir HDR source</th>
<th>Container for ¹³¹I bulk solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radionuclide(Ci)</td>
<td>Ir-192 : 120 Co-60 : 0.11 Cs-137 : 10.8 Tm-170 : 200</td>
<td>Ir-192 : 10 x 2ea</td>
<td>I-131 : 20</td>
</tr>
<tr>
<td>Shielding Material &amp; Absorber</td>
<td>Depleted Uranium Stainless Steel Polyurethane foam</td>
<td>Depleted Uranium Stainless Steel Polyurethane foam</td>
<td>Lead Stainless Steel</td>
</tr>
<tr>
<td>Size(mm)</td>
<td>250 X 151 X256 (L X D X H)</td>
<td>194 X 269 (O.D X H)</td>
<td>300 X 335 (O.D X H)</td>
</tr>
<tr>
<td>Weight(kg)</td>
<td>16</td>
<td></td>
<td>35</td>
</tr>
<tr>
<td>Application Regulation</td>
<td>Korea MOST Notice 96-38 IAEA Safety Standard Series ST-1</td>
<td>Korea MOST Notice 96-38 IAEA Safety Standard Series ST-1</td>
<td>-</td>
</tr>
</tbody>
</table>
Transport Container for Supply of RIs

- IR-192 Projector
Container for Ir-192 HDR source
Transport Container for Supply of RIs

- Container for I-131 bulk solution
## Radioisotopes supplied by KAERI

### RI-Reactor Produced

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Total (mCi)</th>
<th>Imported (mCi)</th>
<th>KAERI (mCi)</th>
<th>Share of domestic product (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{192}$Ir</td>
<td>103,876,576</td>
<td>9,025,100</td>
<td>93,851,476</td>
<td>91.2</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>356,292,824</td>
<td>356,268,111</td>
<td>24,713</td>
<td>-</td>
</tr>
<tr>
<td>$^{131}$I</td>
<td>764,844</td>
<td>297,162</td>
<td>467,682</td>
<td>61.1</td>
</tr>
<tr>
<td>$^{99m}$Tc</td>
<td>5,969,853</td>
<td>5,961,070(G)</td>
<td>8,783(S)</td>
<td>0.2</td>
</tr>
<tr>
<td>$^{99}$Mo</td>
<td>11,300</td>
<td>-</td>
<td>11,300</td>
<td>-</td>
</tr>
<tr>
<td>$^{166}$Ho</td>
<td>43,147</td>
<td>-</td>
<td>43,147</td>
<td>100</td>
</tr>
<tr>
<td>$[^{131}]$I$^{m}$lBG</td>
<td>3,056</td>
<td>-</td>
<td>3,056</td>
<td>100</td>
</tr>
<tr>
<td>$^{32}$P</td>
<td>3,165</td>
<td>3,125</td>
<td>40</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>14,894,114</td>
<td>14,894,064</td>
<td>50</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>377,420,000</td>
<td></td>
<td>94,410,247</td>
<td></td>
</tr>
</tbody>
</table>
Future Radioisotope Production Program (I)

- HANARO is routinely utilized to produce radioisotopes for medical ($^{131}$I, $^{166}$Ho, $^{99m}$Tc, $^{51}$Cr) and industrial uses ($^{192}$Ir, $^{60}$Co).

- KAERI is able to supply with $^{192}$Ir, $^{131}$I, $^{32}$P, $^{51}$Cr etc. to international market.

- KAERI is considering large-scale production and cooperation with private companies for the commercial supply of radioisotopes such as fission $^{99}$Mo, $^{60}$Co irradiation sources and $^{192}$Ir sources.
Future Radioisotope Production Program (II)

A New Medical Isotopes Production (MIP) Project

- **Background**
  - To secure continuous and reliable supply of RIs internally and internationally, especially in East-North Asia

- **Features of the MIP**
  - MIP consists of two small reactors (50kW) and a common MI processing facility
  - MI to be recovered are Mo-99, Sr-89/Sr-90, I-131, Xe-133, Cs-137, etc.
  - An aqueous solution of uranyl sulfate using low enriched U(<20 %) are used as a nuclear fuel and target material simultaneously
  - All chemical processing are carried out in closed systems. For example, Mo-99 produced and admixed in the fuel is adsorbed in an adsorption column while the fuel solution is flowing through the column.
Future Strategies

- Establishment of Infrastructure for mass production of RI for commercial supply
- Mass production of RI to meet the domestic demands and Subsequently to supply to international Markets
- Strengthening Cooperative relationship with private Company
  - to be the Hub for RI technology in Asia
- Activation of RI application in industrial and medical purposes
Future R&D activities

- Development of disease targeting diagnostic and therapeutic radiopharmaceuticals using disease specific ligands, peptide and antibody for the medical application

- Development of radiation sources and equipment for utilizing the sources

- Research on separation technologies for short-lived radionuclides from fission products

- Development of technology for fission $^{99}$Mo production using low enriched uranium